Physics 3310
Notes and Problem Sets

Forces and Newton's Laws

Chapter 4
Giancoli

Key!
STUDENT NAME

TEACHER'S NAME

PERIOD

Lesson 1: Dynamics, Mass, Inertia & Force

Definitions

Dynamics - The study of WHY things move.

Mass - 1) The amount of matter that makes up an object.
2) The measure of the ***inertia*** of an object.

Demos:
- Chalk + hoop
- tablecloth
- penny on elbow
- egg into glass

- Mass is a scalar quantity
- The symbol for mass will be lower case "m"
- The units for mass are as follows:

MKS = kilogram (kg)
CGS = gram (g)
English = slug (slug) → not pounds!

Inertia - An objects tendency to maintain its present state of motion.
its an objects tendency to resist a change in motion.

- Inertia is quantitative, the numerical value is the mass number for that object.
- If an object is a rest, the object's inertia is a measure of how much it wants to stay at rest.
- If an object is moving with constant velocity, the object's inertia is a measure of how much it wants to maintain its current speed and direction. A more massive object is harder to stop.

(Refer to Newton's Laws for a more complete explanation)

Force - a push or a pull– it is the "thing" that causes accelerations.

Forces don't keep objects in motion - they cause it to start or stop.

Note: This is a very abstract concept. We can never really talk about acceleration without stating the "thing" that caused the acceleration

For example: The acceleration due to gravity

The acceleration on the baseball due to the bat

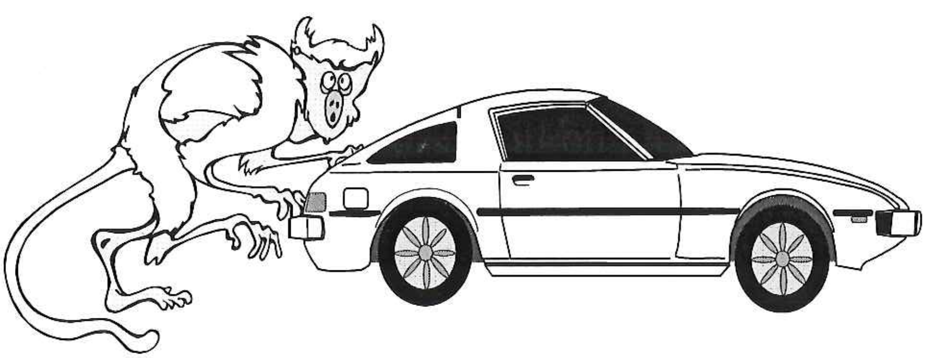
The acceleration of a car due to friction!

- When you exert a push or a pull on an object, you say, you are exerting a force on that object.
- A force cannot be seen, it is only known by its *effects* on an object.

(Refer to Newton's Laws for a more complete explanation)

1st Effect – Forces cause accelerations

But, what if a car is stuck in the mud and a giant monkey pushes (exerting a force) and the car doesn't move (no acceleration). Is he still exerting a force on the car? _____



2 nd Effect – Action-Reaction Law of Motion.

Gallelio Movie

When you push on something, it pushes back at you.

Equal and opposite reactions!

Lesson 1 Problems: Dynamics, Mass, Inertia & Forces

1. Is inertia a force? Explain

No! Inertia is a physical property of matter. Force is a push or pull on that object.

2. If there is no motion can there be a force? _____ Give an example to support your argument.

Yes! You can apply a force to a wall but the wall won't move.

3. Identify which of the following are examples of a force

   a) the pull of a wagon Force

   b) the push of a hand Force

   c) the mass of a nickel is 5.0 grams Inertia

4. What is required in order for a force to be present?

An object to apply the force to.

Lesson 2. Newton's Three Laws of Motion

Newton's Three Laws of Motion

1st Law (The law of inertia) – An object will continue in its state of rest or constant velocity (both magnitude and direction) unless acted on by a **NET** force.

- The **NET** Force is defined as *the Sum of* all the force vectors acting on an object. The Greek letter upper case sigma "Σ" means "*the sum of*".
  Therefore, ΣF will mean **NET** force.
- If the Net Force (ΣF) equals zero then Acceleration **Must** also equal zero!
- This is a change from Aristotle's belief that a body's natural state is at rest. Newton shows a body's natural state is whatever state it has at present. examples: • in a car – seatbelts locking • skateboarder hitting curb • us moving with earth

Question

1. Can an object have forces acting on it and NOT be accelerating? Explain your answer.

   Yes! There is only acceleration when net force is zero. Two forces can have ΣF = 0.

2. If an object has a zero net force acting on it, does this mean there are no forces acting on the object? Explain your answer.

   No! Think of a book: gravity pulls down and table pushes up. Two forces are acting, but they balance out so zero net force

2nd Law $(\vec{F} = m\vec{a})$ - The acceleration of an object is directly proportional to the **NET** force on it, and inversely proportional to its mass. The direction of the acceleration vector will be in the direction of the **NET** force vector. $\vec{a} = \frac{\Sigma\vec{F}}{m}$

- The second law shows from where the units for force are derived.

(Acceleration) (Mass) = Force

MKS $\left(1_{\frac{m}{s^2}}\right)\left(1_{kg}\right) = 1_{Newton} = 1_N$

CGS $\left(1_{\frac{cm}{s^2}}\right)\left(1_{g}\right) = 1_{dyne}$

English $\left(1_{\frac{ft}{s^2}}\right)\left(1_{slug}\right) = 1_{pound} = 1_{lb}$

- The second law also helps to quantify the idea of inertia.

Example:

A Force equal to $+10_N\hat{x}$ is applied to two different masses. $m_1 = 10$ kg and $m_2 = 100$ kg

A comparison of the two object's acceleration will show which object has the greater inertia.

$$\vec{a}_1 = \frac{\Sigma\vec{F}}{m_1} = \frac{10_N\hat{x}}{10_{kg}} = 1_{\frac{m}{s^2}}\hat{x} \qquad \vec{a}_2 = \frac{\Sigma\vec{F}}{m_2} = \frac{10_N\hat{x}}{100_{kg}} = 0.1_{\frac{m}{s^2}}\hat{x}$$

Remember, acceleration is inversely proportion to the inertia of an object. Therefore m_2 must have 10 times more inertia than m_1, because it has 10 time less acceleration.

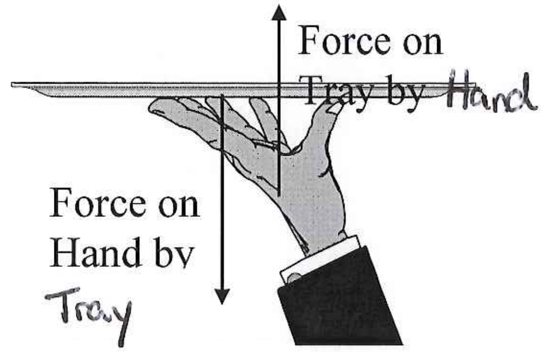
For same ΣF, object with greater mass will accelerate less!

<u>3rd Law (Action/Reaction forces)</u> – When one object exerts a force on a second object, the second object will exert a force on the first object. The second force will be equal in magnitude but opposite in direction to the first force.

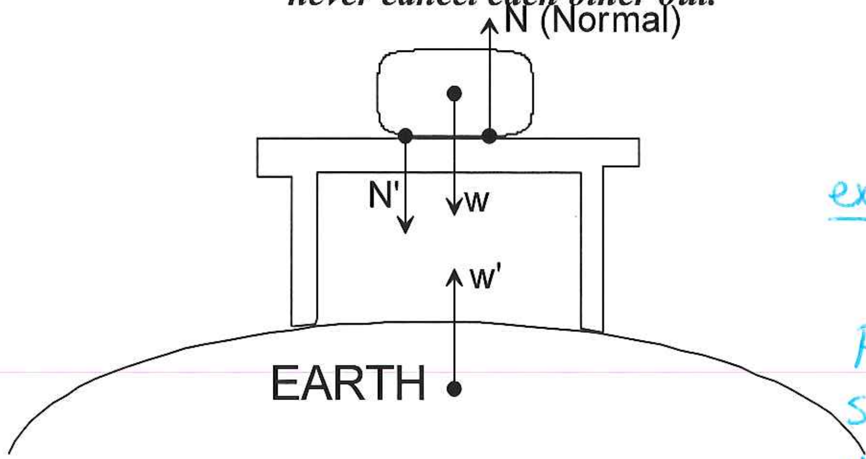
- Forces always come in pairs.
- Using the "**<u>on</u>**" & "**<u>by</u>**" terms

<u>Action</u> – The force exerted *on* the *tray* **by** the *hand.*

<u>Reaction</u> – The force exerted **on** the *hand* **by** the *tray*.



Note: the action reaction forces do NOT act on the same object, and therefore can never cancel each other out.



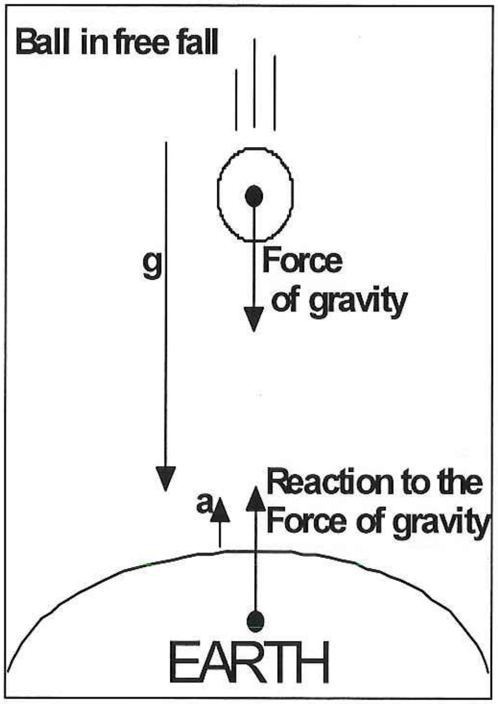
example: this is why we can walk! We push down on floor so floor pushes up on us so we move forward

<u>ACTION – REACTION PAIRS</u>

w = weight force, force exerted <u>on</u> the block <u>by</u> the earth.
w' = force <u>on</u> the earth <u>by</u> the block.

N = surface force, force <u>on</u> the block <u>by</u> the table
N' = force <u>on</u> the table <u>by</u> the block

** Common Misconception – the weight and the force normal are an action/reaction pair. ***<u>NOT TRUE!!!</u>*** They are often equal in magnitude and opposite in direction, but they are not an action/reaction pair.

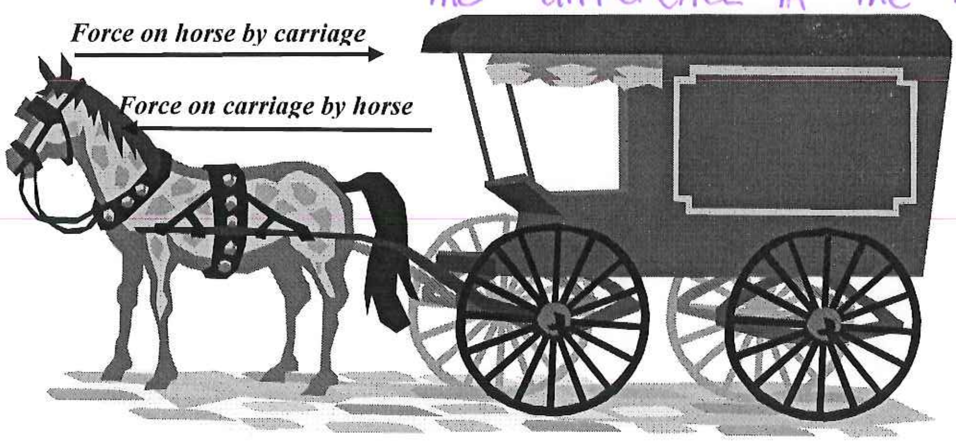


- According to Newton's 3[rd] Law, when any object falls to the earth there is a force exerted **by** the object **on** the earth.
- Therefore, the earth should accelerate just as the ball does.
  - IT DOES!! However, the accelerations are inversely proportional to the masses.

$$\Sigma F = \Sigma F$$

$$m_{earth} a_{earth} = m_{ball} a_{ball}$$

The force is the same, it is the acceleration that is different due to the difference in the masses.



According to legend, a talking horse (we will call him Wilber) learned Newton's laws. When he was told to pull the carriage, he refused; saying that when he pulls on the carriage forward, Newton's 3[rd] law states the carriage will pull on him with an equal force in the opposite direction. Therefore, the forces would be balanced, and there would be no **NET** force. Wilber then goes on to say that since there is no **NET** force Newton's 1[st] and 2[nd] laws state there can be no acceleration. How would you reason with this rather weird horse?

Action-reaction pairs never act on the same object so they don't balance out to no net force. He pushes on the ground which pushes him forward (he has a net force). He just needs to push on the ground harder than the carrige pulls on him.

Lesson 2 Problems: Newton's Three Laws of Motion **Problems**

1. A net force of 255 N accelerates a bike and rider at 2.20 m/s^2. What is the mass of the bike and rider?

   $\Sigma F = 255N$ $\quad \Sigma F = ma$
   $a = 2.2 m/s^2$ $\quad 255 = m(2.2)$
   $m = ?$ $\quad m = 115.9kg$

2. How much force is required to accelerate a 9.0-g object at 10,000 "g's" (say, in centrifuge)?

   $m = .009kg$ $\quad \Sigma F = ma$
   $a = 10{,}000(9.8) m/s^2$ $\quad = .009(10{,}000)(9.8)$
   $\Sigma F = ?$ $\quad \Sigma F = 882N$

3. How much tension must a rope withstand if it is used to accelerate a 1050-kg car horizontally at 1.20 m/s^2? Ignore friction.

   $m = 1050kg$ $\quad \Sigma F = ma$
   $a = 1.2 m/s^2$ $\quad = 1050kg(1.2 m/s^2)$
   $\Sigma F = ?$ $\quad \Sigma F = 1260N$

4. What is the weight of a 66-kg astronaut (a) on Earth, (b) on the Moon (g=1.7 m/s^2), (c) on Mars (g= 3.7 m/s^2), (d) in outer space traveling with constant velocity?

   Weight = $F_g = mg$
   a. $F_g = 66(9.8) = 646.8N$ $\quad$ c. $66(3.7) = 244.2N$
   b. $F_g = 66(1.7) = 112.2N$ $\quad$ d. $66(0) = 0N$

5. A 20.0-kg box rests on a table. (a) What is the weight of the box and the normal force acting on it? (b) A 10.0-kg box is placed on top of the 20.0-kg box, as shown in Fig. 4-35. Determine the normal force that the table exerts on the 20.0-kg box and the normal force that the 20.0-kg box exerts on the 10.0-kg box.

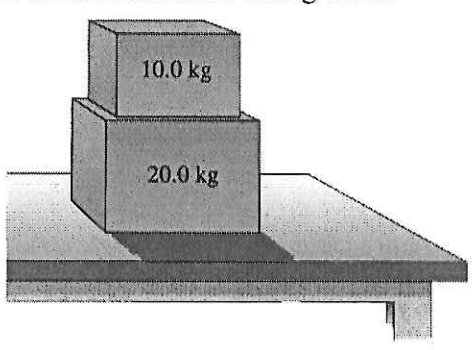


FIGURE 4-35

   a. $F_g = mg = 20(9.8) = 196N$ DOWN
   So Table pushes up 196N.

   b. Table holds them both up so it must equal weight of both: $F_g = 30(9.8) = 294N$ up.
   The 20kg holds up just the 10kg so $10(9.8) = 98N$ up.

6. What average force is needed to accelerate a 7.00-gram pellet from rest to 175 m/s over a distance of 0.700 m along the barrel of a rifle? (Remember kinematics)

$V_i = 0 m/s$
$V_f = 175 m/s$
$\Delta x = .7 m$
$a = ?$
$\Sigma F = ?$

$V_f^2 = V_i^2 + 2a\Delta x$
$175^2 = 0^2 + 2a(.7)$
$a = 21,875 m/s^2$

$\Sigma F = ma$
$= .007(21875)$
$\Sigma F = 153.125 N$

Lesson 3: Concept Questions – Newton's Three Laws of Motion

1. Why does a child in a wagon seem to fall backward when you give the wagon a sharp pull?

He has inertia so he wants to stay where he is but the wagon moves forward.

2. Why do you push harder on the pedals of a bicycle when first starting out than when moving with a constant speed?

You need to apply a net force to cause acceleration

3. Only one force acts on an object. Can the object have zero acceleration? Can it have zero velocity?

No. If there is only one force, you have a ΣF so there must be an acceleration.

Yes. An object thrown up → $a = -9.8 m/s^2$ BUT AT top, $v = 0 m/s$.

4. The force of gravity on a 2 kg rock is twice as great as that on a 1 kg rock. Why then doesn't the heavier rock fall faster?

its acceleration is the same. $a = \frac{\Sigma F}{m} = \frac{F_g}{m} = \frac{mg}{m} = g$ MASS Doesn't matter

5. A person exerts an upward force of 40 N to hold a bag of groceries. Describe the "reaction" force (Newton's third law) by stating (a) its magnitude, (b) its direction, (c) *on* what body it is exerted, and (d) *by* what body it is exerted.

a. 40N b. Down c. on the person d. by the bag

6. When you stand still on the ground, how large a force does the ground exert on you? Why doesn't this force make you rise up into the air?

The same as your weight.
gravity pulls back on you.
Overall, no net force, so no acceleration!

Lesson 3: The four fundamental forces

THE FOUR FUNDAMENTAL FORCES

- Scientists have worked very hard to find a commonality between all forces in the universe. They are trying to prove that all forces are components or properties of a single *Grand Unifying Force*. So far the scientists have unsuccessful.
- Instead of one force, they have grouped all forces into four categories.

Important note: All of these forces act at a distance. (No contact at the microscopic level)

1) ***Gravitational Forces***
   - Attractive forces that exists between all objects.
   - Caused by the interaction between the objects gravitational fields
   - Infinite Range, weakest force, Relative force = 10^{-38}

2) ***Electromagnetic Forces***
   - Force that exists between all charged particles or particles that demonstrate magnetic properties.
     (Protons, electrons, molecular bonding)
   - Force that holds all matter together
   - Infinite Range, Relative strength = 10^{-2}

3) ***Strong Nuclear Force***
   - The force that holds the nucleus of the atom together.
   - Overcomes the natural electromagnetic repulsion of protons
   - Range $\leq$ to the diameter of an atom, Strongest force, Relative strength = 1

4) ***Weak Nuclear Force***
   - Force that causes the radioactive decay of some nuclei
   - Modern Theory has linked the weak nuclear force with the electromagnetic force with a theory known as *electroweak* theory
   - Range $\leq$ the diameter of an atom, Relative strength = 10^{-6}

Theories such as the *electroweak* theory have recently lead to attempts to complete a ***Grand Unification Theory***; a theory that would tie all the fundamental forces together, as well as revolutionize the study of physics.

Lesson 4: Common Forces

Force due to Gravity (A.K.A. "weight force")

$$\vec{F}_g = (m)(\vec{a}_g) = (m)(g)$$

Where $\vec{F}_g$ = weight, m = mass and g = acceleration due to gravity $-9.8_{\frac{m}{s^2}}\hat{y}$

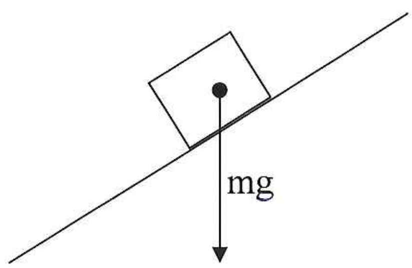
$$\vec{F}_g = (1.00_{kg})(-9.80_{\frac{m}{s^2}}) = -9.80_N\,\hat{y}$$

Therefore, the weight of 1 kg on the earth is 9.8 Newtons,

$$\vec{F}_g = (1.00_{kg})(-1.67_{\frac{m}{s^2}}) = -1.67_N\,\hat{y}$$

But only 1.67 Newtons on the moon, where "g" is less.

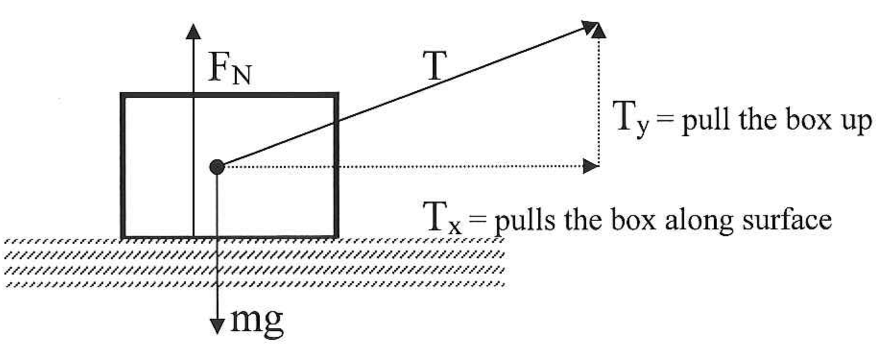
- Force due to gravity always acts straight down, even if the mass is on an incline.



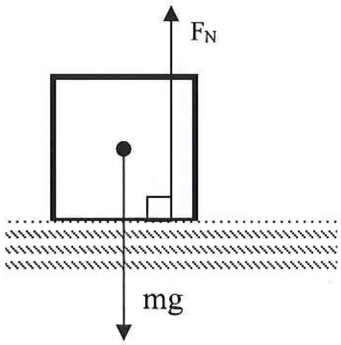
Tension Forces - force of strings, ropes, cables

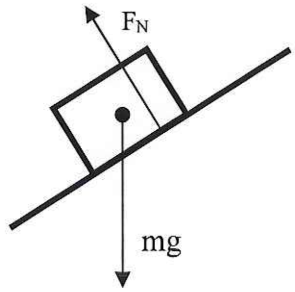
- Tension forces pull, never push
- Tension forces always act along the string
- Tension force is a reactive force

(something must pull on the rope to have tension in the rope)



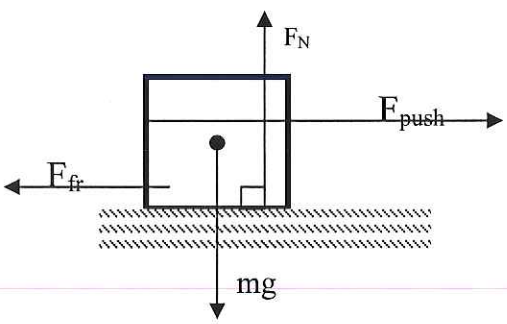
The Normal Force = surface force of a table, the ground, etc. straight up (90°) from the surface.





- The Force Normal, F_N, is reactive, not pro-active
- F_N always acts perpendicular to the surface, even if the mass is on an incline.
- F_N is not always equal to the weight force (mg) – it may be increased or reduced by an third force acting in the vertical plane

Friction – Surface force that acts parallel to the surface and resists the tendency for sliding.



- The Friction force is a reactive force, not pro-active
- only present if F_{push} is present
- $F_{fr} = \mu F_N$

What is μ ?

- Greek Letter "mu"; represents the ***coefficient of friction***
- Numerically the ***coefficient of friction*** is a ratio between two forces
- Unit-less number that characterizes friction between two surfaces
    - Every two surfaces in contact have their own value for μ
- Types of μ
    - μ_s = coefficient of static friction
    - μ_k = coefficient of kinetic friction

Experimentally it can be found:

1) $\mu_s > \mu_k$
2) μ_s and μ_k are independent of the surface area in contact

Question: The value for μ is found experimentally. What type of an experiment could you do to calculate μ?

Example: Constant Force Problem (Sum the Forces Problem)

A 10 kg object is subjected to the two forces F_1 and F_2, as shown below.

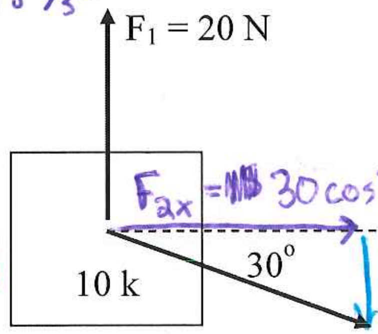
a.) Find the acceleration of the object
b.) If the object is at rest at t = 0 how fast is it moving after 3s.?
c.) Find the third force F_3 needed so that the object is in static equilibrium.

a. $\Sigma F_x = 25.98N = 10kg(a_x) \rightarrow a_x = 2.598 m/s^2$

$\Sigma F_y = 5N = 10kg(a_y) \rightarrow a_y = .5 m/s^2$

$\therefore a = \sqrt{2.598^2 + .5^2} = 2.645 m/s^2$

$\theta = \tan^{-1}(.5/2.598) = 10.89°$



$F_{2x} = 30\cos 30 = 25.98N$

$F_{2y} = 30\sin 30 = 15N$

b. $V_i = 0 m/s$
$a = 2.645 m/s^2$
$t = 3 sec$

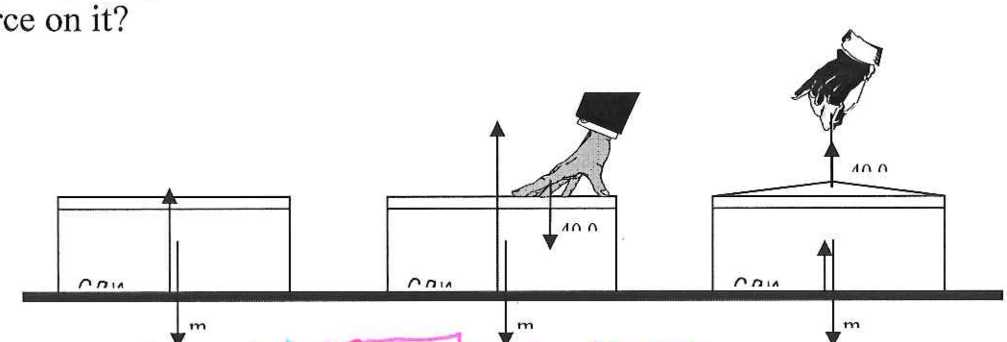
$V_f = V_i + at$
$= 0 + 2.645(3)$
$V_f = 7.937 m/s$

c. $F_3 = -25.98N\hat{x} - 5N\hat{y}$

Example: Normal Force Problem

A 10 kg box of chocolates is resting on a smooth (frictionless) horizontal surface of a table.

a.) Determine the weight of the box and the normal force acting on it.
b.) Now you push down on the box with a force of 40 N. Again determine the box's weight and the normal force acting on it.
c.) If you pull upward with a force of 40 N, what is the box's weight and the normal force on it?



a. $F_g = 10kg(9.8 m/s^2) = 98N$; $F_N = 98N$

b. $F_g = 10kg(9.8 m/s^2) = 98N$; $F_N = 98N + 40N = 138N$

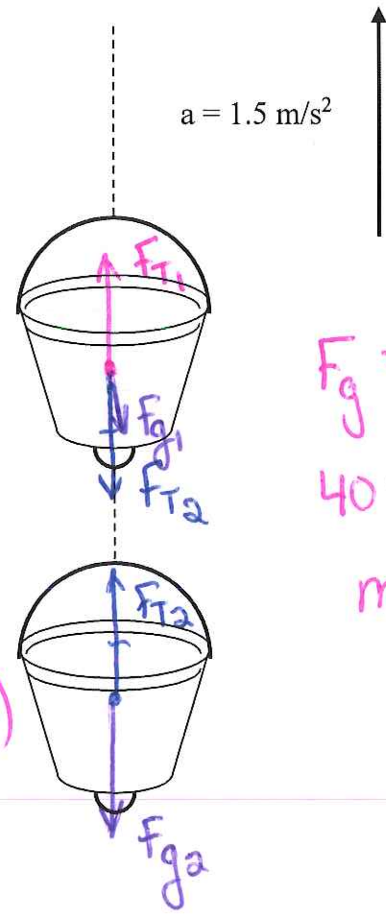
c. $F_g = 10kg(9.8 m/s^2) = 98N$, $F_N = 98N - 40N = 58N$

Example: Tension Problem

One paint bucket weighting 40 N is hanging from a massless cord from another bucket also weighing 40 N. The two are being pulled upward with an acceleration of 1.5 m/s^2 by a massless cord attached to the upper bucket. Calculate the tension in each cord.

Top Bucket:

$$\Sigma F = F_{T_1} - F_{g_1} - F_{T_2} = ma$$



Bottom Bucket:

$$\Sigma F = F_{T_2} - F_g = ma$$

$$F_{T_2} - mg = ma$$

$$F_{T_2} = 4.08(1.5) - 4.08(9.8)$$

$$\boxed{F_{T_2} = 46.122\text{N}}$$

$$F_g = mg$$

$$40 = m(9.8)$$

$$m = 4.08\text{kg}$$

Back To Top Bucket:

$$F_{T_1} - 40 - 46.122 = 4.08(1.5)$$

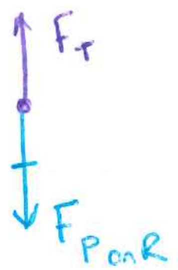
$$\boxed{F_{T_2} = 92.24\text{N}}$$

Example: Person pulling on the rope Tension Problem

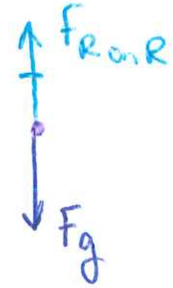
A 75 kg person is accelerating at a rate of 0.5 m/s² upward while climbing a rope attached to the ceiling.

a.) Draw a force diagram of the rope showing all of the forces acting on ropes
b.) Draw a force diagram of the person showing all of the forces acting on the person
c.) What force is pulling the person upward?
d.) Calculate the tension force in the rope.

a.



b.



c. They pull on the rope so the rope pulls on them.

d. Look at person:

$$\Sigma F = F_{R\,on\,P} - F_g = ma$$

$$F_{R\,on\,P} - mg = ma$$

$$F_{R\,on\,P} = 75(1.5) + 75(9.8)$$

$$F_{R\,on\,P} = 772.5\,N$$

By Newton's 3rd Law, $F_{P\,on\,R}$ is also 772.5N.

Since rope isn't moving, $\Sigma F = 0$ so $F_T = F_{R\,on\,R}$

$$\therefore \boxed{F_T = 772.5N}$$

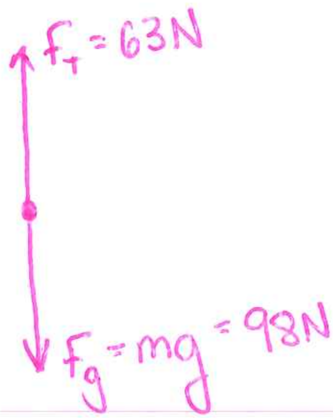
Lesson 4 Problems: Common Forces

Problems

1. How much tension must a rope withstand if it is used to accelerate a 1200-kg car vertically upward at 0.80 m/s^2? Ignore friction.

$$\Sigma F = F_T - F_g = ma$$
$$F_T - mg = ma$$
$$F_T = 1200(.8) + 1200(9.8) \rightarrow \boxed{F_T = 12{,}720N}$$

2. A 10-kg bucket is lowered by a rope in which there is 63 N of tension. What is the acceleration of the bucket? Is it up or down?



$$\Sigma F = F_T - F_g = ma$$
$$63 - 98 = 10a$$
$$\boxed{a = -3.5 m/s^2}$$

3. An elevator (mass 4850 kg) is to be designed so that the maximum acceleration is 0.0600 g. What are the maximum and minimum forces the motor should exert on the supporting cable?

$$a = .06(9.8) = .588 m/s^2$$

MAX TENSION when accelerating upwards:

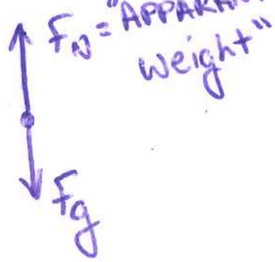
$$\Sigma F = F_T - F_g = ma$$
$$F_T - mg = ma$$
$$F_T = 4850(.588) + 4850(9.8)$$
$$\boxed{F_T = 50{,}381.8N}$$

min when accelerating downwards ($a = -.588$)

$$F_T = 4850(-.588) + 4850(9.8)$$
$$\boxed{F_T = 44{,}678.2N}$$

4. A person stands on a bathroom scale in a motionless elevator. When the elevator begins to move, the scale briefly reads only 0.75 of the person's regular weight. Calculate the acceleration of the elevator, and find the direction of acceleration.

Define up as positive.



$$\Sigma F = F_N - F_g = ma$$
$$.75F_g - F_g = ma$$
$$.75mg - mg = ma$$
$$-.25g = a \rightarrow \boxed{a = -2.45\,m/s^2}$$

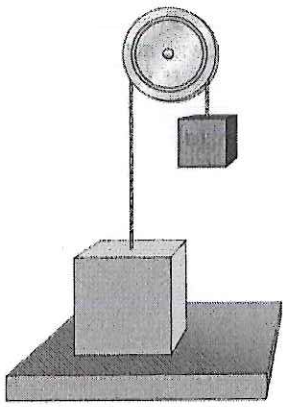


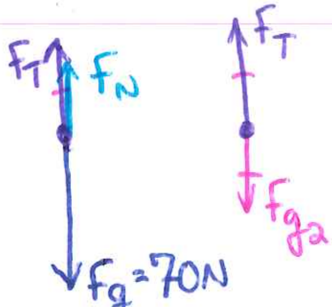
FIGURE 4–37

5. A box weighing 70 N rests on a table. A rope tied to the box runs vertically upward over a pulley and a weight is hung from the other end (Figure 4-37). Determine the force that the table exerts on the box if the weight hanging on the other side of the pulley weighs (a) 30 N (b) 60 N, and (c) 90 N.

F_T is the same as F_{ga} therefore:

a. $\Sigma F = -F_g + F_T + F_N = 0$ Since its at rest

$-70 + 30 + F_N = 0 \Rightarrow \boxed{F_N = 40N}$

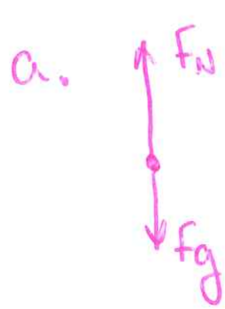


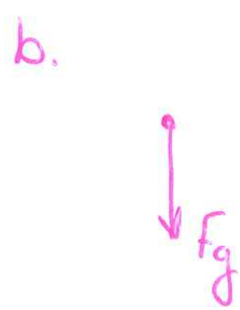
b. $-F_g + F_T + F_N = 0$

$-70 + 60 + F_N = 0 \Rightarrow \boxed{F_N = 10N}$

c. $-70 + 90 + F_N = 0 \Rightarrow \boxed{F_N = -20N}$ NOT Possible!

6. Draw the free-body diagram for a basketball player (a) just before leaving the ground on a jump, and (b) while in the air. (Fig. 4-38)





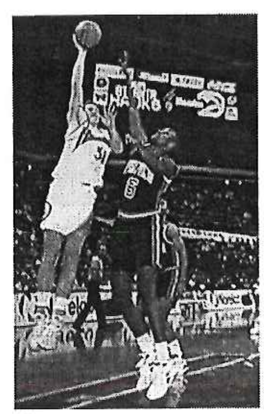
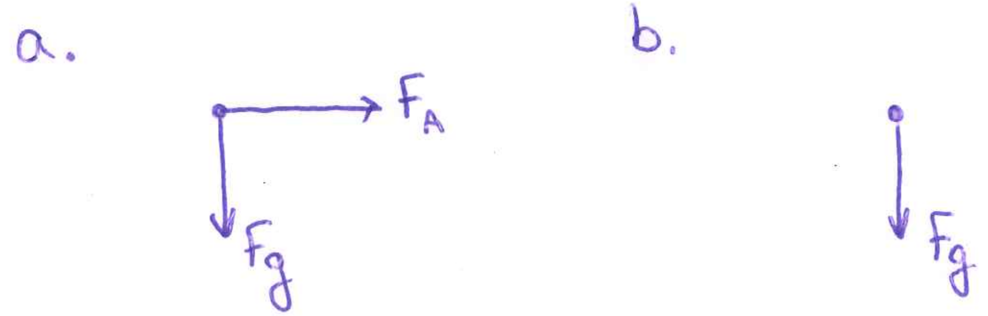


FIGURE 4–38

7. Sketch the free-body diagram of a baseball (a) at the moment it is hit by that bat, and again (b) after it has left the bat and is flying toward the outfield.



8. The two forces F_1 and F_2 shown in Fig. 4-39a and b (looking down) act on a 27.0-kg on a frictionless tabletop. If $F_1 = 10.2$ N and F_2 16.0 N, find the net force on the object and its acceleration for each situation, (a) and (b).

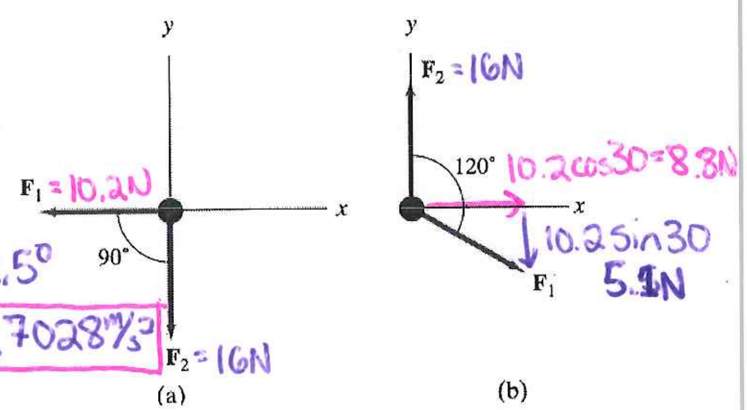


FIGURE 4-39

a. $\Sigma F = -10.2N\hat{x} + 16N\hat{y} = 18.97N @ 32.5°$

$\Sigma F = ma \rightarrow 18.97 = 27a \rightarrow$ $a = .7028 m/s^2$

b. $\Sigma F = 8.8N\hat{x} + (16 - 5.1)N\hat{y}$

$= 8.8N\hat{x} + 10.9N\hat{y} = 14.01N @ 26.25°$

$\Sigma F = ma \rightarrow 14.01 = 27a \rightarrow$ $a = .519 m/s^2$

Lesson 4: Concept Questions – Common Forces

1. If the acceleration of a body is zero, are no force acting on it? Not necessarily. No ΣF is.

2. Why is the stopping distance of a truck much shorter than for a train going the same speed?

   The train has more mass so it requires more force to accelerate it.

3. Can a coefficient of friction exceed 1.0?

   No! $\mu = F_f / F_N$ and $F_f \leq F_N$.

4. A heavy crate rests on the bed of a flatbed truck. When the truck accelerates, the crate remains where it is on the truck, so it too, accelerates. What force causes the crate to accelerate?

   The frictional force

5. You can hold a heavy box against a rough wall and prevent it from slipping down by pressing only horizontally. How can the application of a *horizontal* force keep an object from moving vertically?

   Pressing against the wall increases F_N and therefore increases F_f since $F_f = \mu F_N$.

Lesson 5: Friction- A closer look

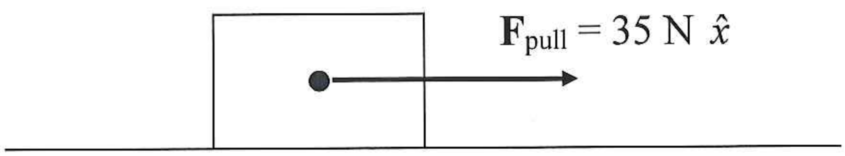
Friction (static vs kinetic)

Recall: $\vec{F}_{fr} = \mu \vec{F}_N$

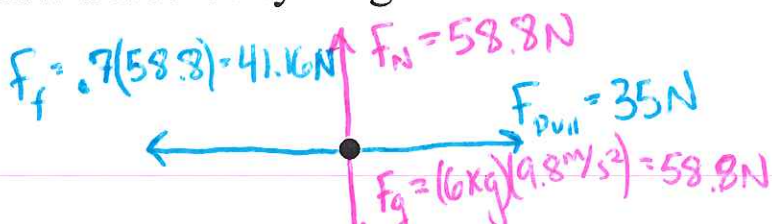
What happens when the frictional force is bigger than the applied force?

m = 6 kg

$\mu_{static} = \mu_{kinetic} = 0.7$



1. Draw a free-body diagram for the block above.



2. Use Newton's 2nd law ($\sum \vec{F} = m\,\vec{a}$) to calculate the acceleration.

$\Sigma F = F_{pull} - F_f = ma$

$35 - 41.16 = 6a \rightarrow$ $a = -1.03 m/s^2$

This can't be! friction can't cause something to move backwards.

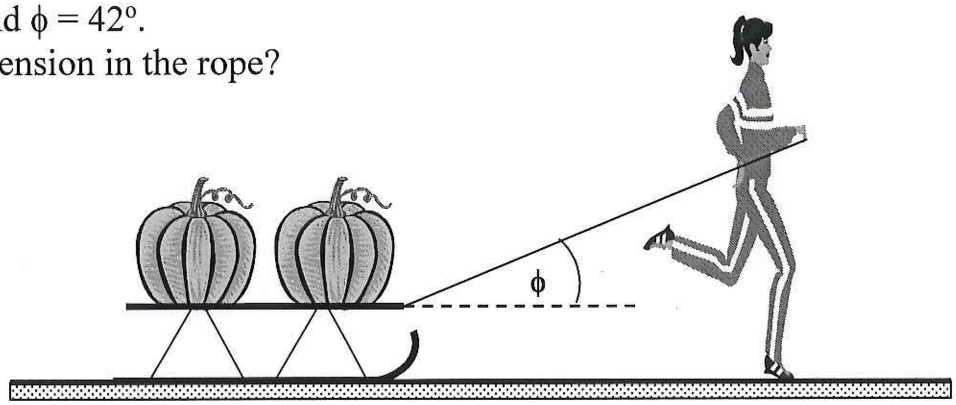
3. What is the frictional force?

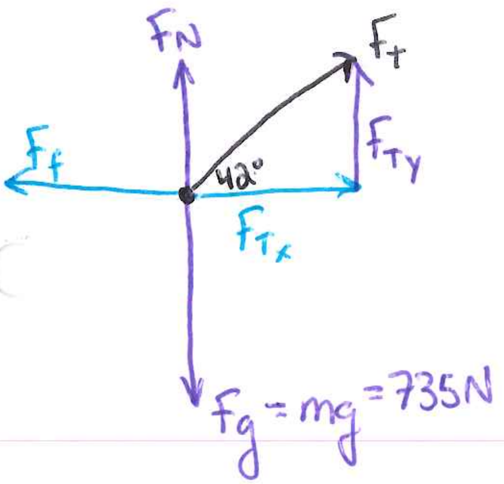
35N. Friction can never be larger than the applied force.

Friction and the Normal Force

A woman pulls a loaded sled of mass, m = 75kg, along a horizontal surface at a constant velocity. The coefficient of kinetic friction, μ_k, between the runners and the snow is 0.10 and $\phi = 42^o$.

a) What is the tension in the rope?





Since sled is moving a constant $\vec{v}$, ΣF_x and ΣF_y both must be zero.

$\Sigma F_x = F_T \cos 42 - F_f = 0$ $\quad \Sigma F_y = F_N + F_T \sin 42 - F_g = 0$

$F_T \cos 42 - \mu F_N = 0$ $\quad F_N = F_g - F_T \sin 42$

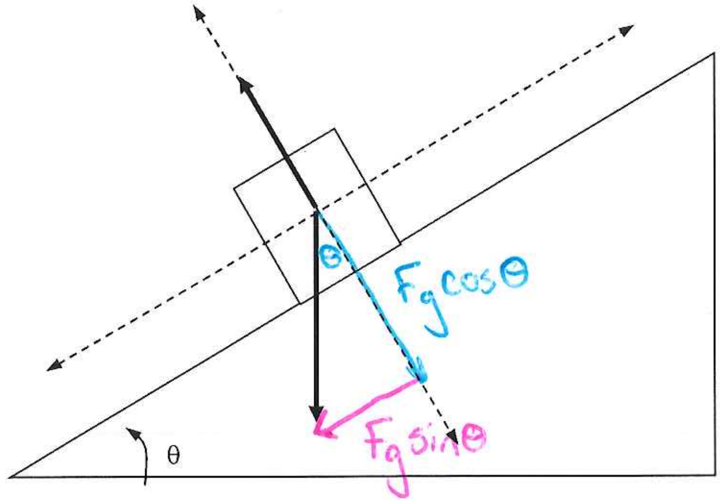
$$F_T \cos 42 - \mu (F_g - F_T \sin 42) = 0$$

$$F_T \cos 42 - .1(735) + .1 F_T \sin 42 = 0$$

$$F_T (\cos 42 + .1 \sin 42) = 73.5$$

$$\boxed{F_T = 90.73N}$$

Inclined Plane Problems



Problem Solving

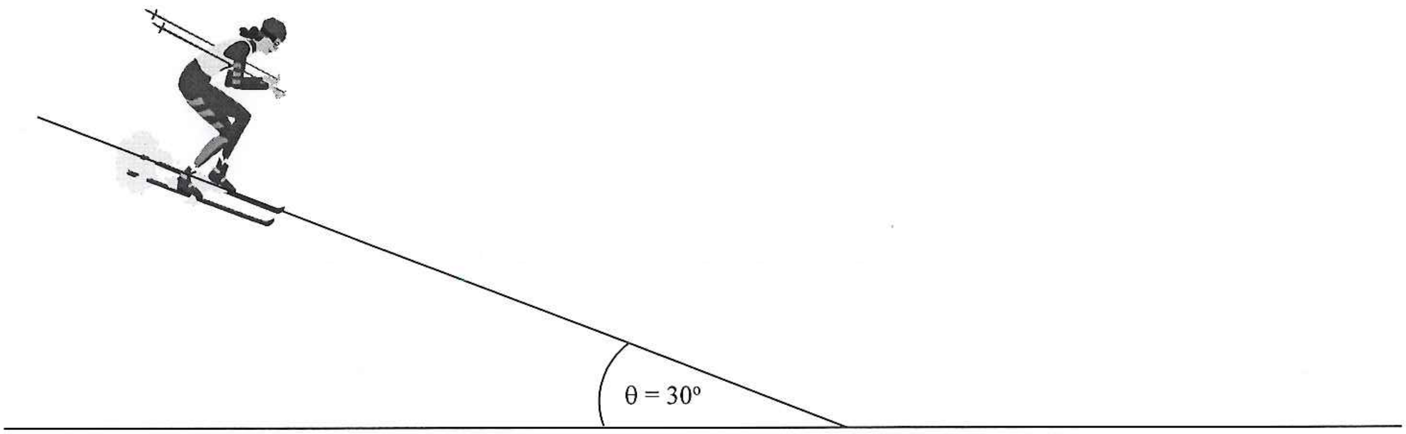
1. Always put the x-y axis so that the y-axis is perpendicular the plane and the x-axis is parallel to the plane (in other words ROTATE THE COORDINATE SYSTEM!)
2. Make sure the weight force ($F_g = mg$) is straight down
3. Identify all other forces, draw vectors on the rotated x-y axis
4. Use $\Sigma F_x = ma_x$ and $\Sigma F_y = ma_y$ to solve the problems

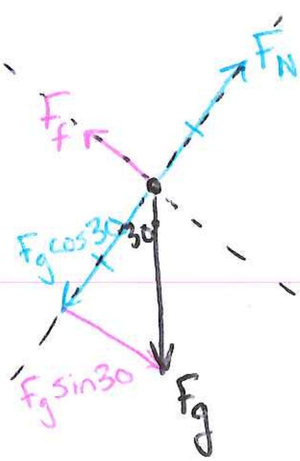
Example Problem – Incline plane

The skier has just begun descending the 30° slope. Assuming the coefficient of kinetic friction is 0.01, calculate

a) the acceleration of the skier.

b) The speed of the skier after 6.0 s.





a. $\Sigma F_x = F_g \sin 30 - F_f = ma$

$mg \sin 30 - \mu F_N = ma$

$mg \sin 30 - \mu (F_g \cos 30) = ma$

$mg \sin 30 - \mu mg \cos 30 = ma$

$a = 9.8 \sin 30 - .01(9.8) \cos 30$

$a = 4.815\ m/s^2$

b. $v_i = 0\ m/s$

$a = 4.89\ m/s^2$

$t = 6\ sec$

$v_f = ?$

$v_f = v_i + at$

$= 0 + 4.815(6)$

$\therefore\ v_f = 28.89\ m/s$

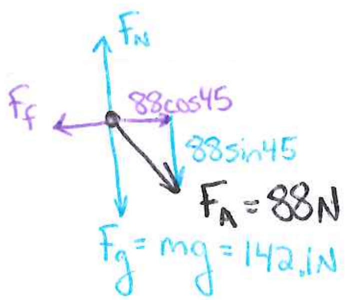
Lesson 5 Problems: Friction – A Closer Look

Problems

FIGURE 4–40

1. A person pushes a 14.5-kg lawn mower at constant speed with a force of 88.0 N directed along the handle, which is at an angle of 45.0° to the horizontal (Fig. 4-40). (a) Draw the free-body diagram showing all forces acting on the mower. Calculate (b) the horizontal retarding force on the mower, then (c) the normal force exerted vertically upward on the mower by the ground, and (d) the force the person must exert on the lawn mower to accelerate it from rest to 1.5 m/s in 2.5 seconds (assuming the same retarding force).

a.



b. $F_f = ?$ $\Sigma F_x = 0$ since constant $\vec{v}$

$\Sigma F_x = 88\cos 45 - F_f = 0 \Rightarrow \boxed{F_f = 62.23N}$

c. $\Sigma F_y = 0$ since no motion in y-direction

$\Sigma F = F_N - F_g - 88\sin 45 = 0$

$F_N - 142.1 - 88\sin 45 = 0 \Rightarrow \boxed{F_N = 204.33N}$

d. $v_i = 0 m/s$, $v_f = 1.5 m/s$, $t = 2.5 sec$, $a = ?$

$v_f = v_i + at$

$1.5 = 0 + a(2.5)$

$a = .6 m/s^2$

$\Sigma F_x = F_A\cos 45 - F_f = ma$

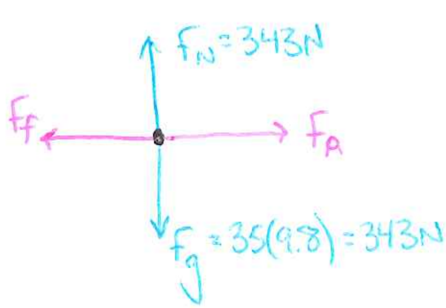
$F_A\cos 45 - 62.23 = 14.5(.6)$

$\boxed{F_A = 100.31N}$

2. If the coefficient of kinetic friction between a 35-kg crate and the floor is 0.30, what horizontal force is required to move the crate at a steady speed across the floor? What horizontal force is required if μ_k is zero?

$m = 35kg$

$\mu_k = .3$



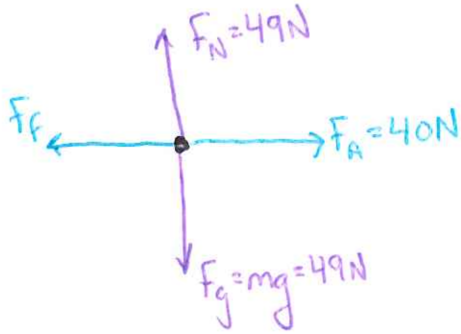
$\Sigma F_x = F_A - F_f = 0$

$F_A - \mu F_N = 0$

$F_A = .3(343) \rightarrow \boxed{F_A = 102.9N}$

If $\mu_k = 0$, Then $\boxed{F_A = 0N}$

3. A force of 40.0 N is required to start a 5.0-kg box moving across a horizontal concrete floor. (a) What is the coefficient of static friction between the box and the floor? (b) If the 40.0-N force continues, the box accelerates at 0.70 m/s². What is the coefficient of kinetic friction?



a. In order to start it moving, the 40N must be just slightly bigger than F_f.

$\Sigma F = F_A - F_f \geq 0$

$F_A - \mu F_N \geq 0$

$40 - \mu(49) \geq 0 \rightarrow \boxed{\mu_s = .816}$

b. Now we have an acceleration:

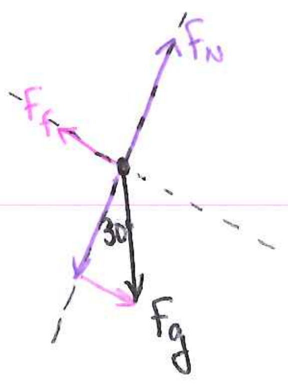
$F_A - F_f = ma$

$F_A - \mu F_N = ma \rightarrow 40 - \mu(49) = 5(.7)$

$\boxed{\mu = .745}$

4. (a) A box sits at rest on a rough 30° inclined plane. Draw the free-body diagram, showing all the forces acting on the box. (b) How would the diagram change if the box were sliding down the plane? (c) How would it change if the box were sliding up the plane after an initial shove?

a:

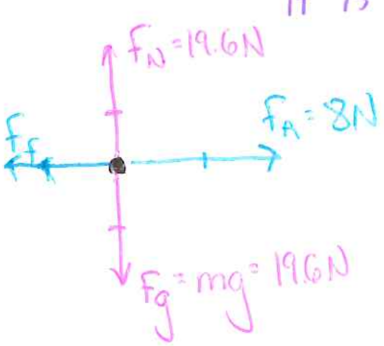


b. $\vec{F}_f$ would be smaller since there would be an acceleration.

c. $\vec{F}_f$ would be in the opposite direction since friction always opposes motion.

5. A 2.0-kg silverware drawer does not slide readily. The owner gradually pulls with more and more force. When the applied force reaches 8.0 N, the drawer suddenly opens, throwing all the utensils to the floor. Find the coefficient of static friction between the drawer and the cabinet.

8N is the "threshold" and you can say when it is at 8N, it is still static friction and not yet accelerating.



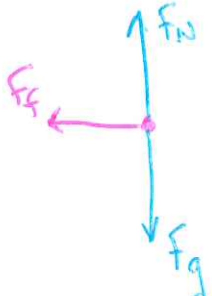
$\Sigma F = F_A - F_f = 0$

$F_A - \mu F_N = 0$

$8 - \mu(19.6) = 0 \rightarrow \boxed{\mu = .408}$

6. A box is given a push so that it slides across the floor. How far will it go, given that the coefficient of kinetic friction is 0.20 and the push imparts an initial speed of 4.0 m/s?

it's given a push, but then stops pushing and friction is slowing it down.



① $\Sigma F = ma$

$-F_f = ma$

$-\mu mg = ma$

$-.2(9.8) = a \rightarrow a = -1.96\ m/s^2$

② now $v_i = 4\ m/s$

$v_f = 0\ m/s$

$a = -1.96\ m/s^2$

$\Delta x = ?$

$v_f^2 = v_i^2 + 2a\Delta x$

$0^2 = 4^2 + 2(-1.96)\Delta x$

$\boxed{\Delta x = 4.08\ m}$

7. (II) Two crates, of mass 75 kg and 110 kg, are in contact and at rest on a horizontal surface (Fig. 4-47). A 730-N force is exerted on the 75-kg crate. If the coefficient of kinetic friction is 0.15, calculate (a) the acceleration on the system, and (b) the force that each crate exerts on the other.

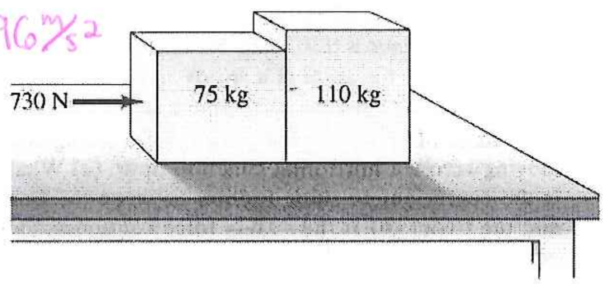
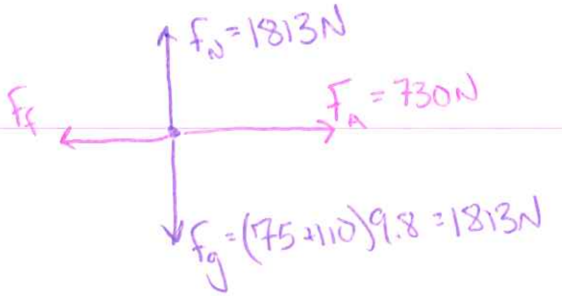


FIGURE 4–47

a. Free body diagram of the system (both boxes):



$\Sigma F_x = F_A - F_f = ma$

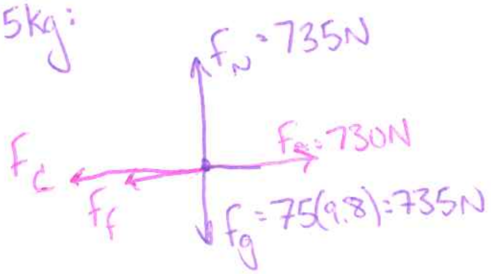
$F_A - \mu F_N = ma$

$730 - .15(1813) = (75+110)a$

$\boxed{a = 2.476\ m/s^2}$

b. Look at one crate individually:

75kg:



$\Sigma F_x = F_A - F_c - F_f = ma$

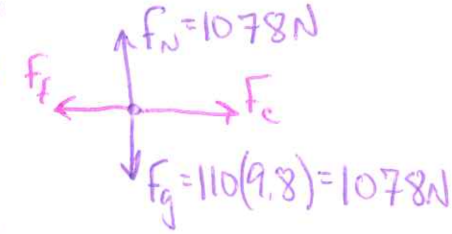
$F_A - F_c - \mu F_N = ma$

$730 - F_c - .15(735) = 75(2.476)$

$\boxed{F_c = 434.05N}$

-OR-

110kg:



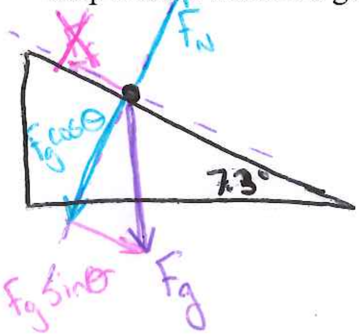
$\Sigma F = F_c - F_f = ma$

$F_c - \mu F_N = ma$

$F_c - .15(1078) = 110(2.476)$

$\boxed{F_c = 434.05N}$

8. A wet bar of soap (mass = 150 grams) slides without friction down a ramp 2.0m long inclined at 7.3°. How long does it take to reach the bottom? Neglect friction. How would this change if the soap's mass were 250 grams?



$\Sigma F_x = F_g \sin 7.3 = ma$

$mg \sin 7.3 = ma$ ← mass doesn't matter!

$a = 1.245\ m/s^2$

$v_i = 0\ m/s$

$\Delta x = 2m$

$a = 1.245\ m/s^2$

$t = ?$

$\Delta x = v_i t + \frac{1}{2}at^2$

$2 = 0 + \frac{1}{2}(1.245)t^2$

$t = 1.79 sec$

θ

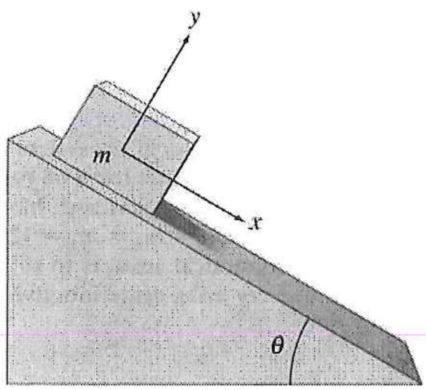
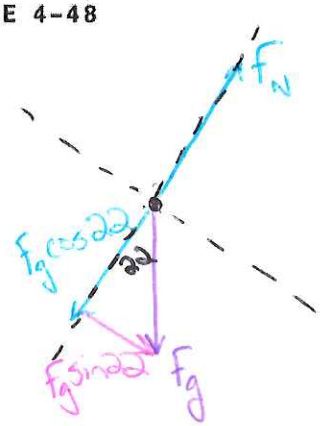


FIGURE 4-48

9. The block shown in Fig. 4-48 lies on a smooth plane tilted at an angle $\theta = 22.0°$ to the horizontal. (a) Determine the acceleration of the block as it slides down the plane. (b) If the block starts from rest 9.10m up the plane from its base, what will be the block's speed when it reaches the bottom of the incline? Ignore friction.



a. $\Sigma F = F_g \sin 22 = ma$

$mg \sin 22 = ma$

$a = 3.67\ m/s^2$

b. $v_i = 0\ m/s$

$\Delta x = 9.1m$

$a = 3.67\ m/s^2$

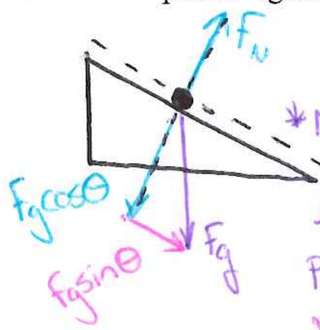
$v_f = ?$

$v_f^2 = v_i^2 + 2a\Delta x$

$= 0^2 + 2(3.67)(9.1)$

$v_f = 8.173\ m/s$

10. A block is given an initial speed of 3.0 m/s up the 22.0° plane shown in Fig. 4-48. (a) How far up the plane will it go? Ignore friction. (b) How much time elapses before it returns to its starting point? Ignore friction. (c) Repeat part (a) but assume a coefficient of friction of 0.08.



a. $\Sigma F = F_g \sin 22 = ma$

$mg\sin 22 = ma$

$9.8\sin 22 = a$

$a = 3.67\ m/s^2$

NOTE: I made down the incline the positive direction

$V_i = -3\ m/s$

$V_f = 0\ m/s$

$a = 3.67\ m/s^2$

$V_f^2 = V_i^2 + 2a\Delta x$

$0^2 = (-3)^2 + 2(3.67)\Delta x$

$\Delta x = -1.22\ m$

b. $t = ?$ $V_f = V_i + at$ Just time to reach top

$0 = -3 + 3.67t \rightarrow t = .817\ sec * 2 = 1.635\ sec$

c. $\Sigma F = F_g \sin 22 + F_f = ma$ + since it is going up, friction is down incline.

$mg\sin 22 + \mu F_n = ma$

$mg\sin 22 + \mu mg\cos 22 = ma$

$a = 9.8\sin 22 + .08(9.8)\cos 22$

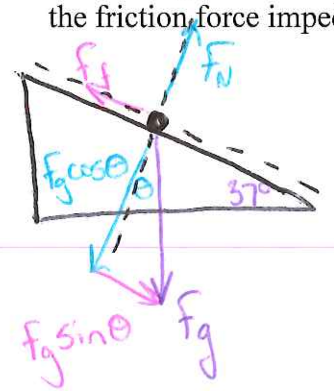
$a = 4.398\ m/s^2$

So $V_f^2 = V_i^2 + 2a\Delta x$

$0 = (-3)^2 + 2(4.398)\Delta x$

$\Delta x = -1.023\ m$

11. An 18.0-kg box is released on a 37.0° incline and accelerates down the incline at 0.270 m/s². Find the friction force impeding its motion. How large is the coefficient of friction?



$\Sigma F = F_g \sin 37 - F_f = ma$

$mg\sin 37 - \mu F_N = ma$

$mg\sin 37 - \mu(F_g\cos 37) = ma$

$mg\sin 37 - \mu mg\cos 37 = ma$

$9.8\sin 37 - \mu\, 9.8\cos 37 = .27$

$\mu_k = .719$

A Little Extra Challenge

1. Figaro the cat (5.0 kg) is hanging on the tablecloth, pulling Cleo's fishbowl (11 kg) toward that edge of the table (Fig. 4-50). The coefficient of kinetic friction between the tablecloth (ignore its mass) under the fishbowl and the table is 0.44. (a) What is the acceleration of Figaro and the fishbowl? (b) If the fishbowl is 0.90 m from the edge of the table, how much time does it take for Figaro to pull Cleo off the table?

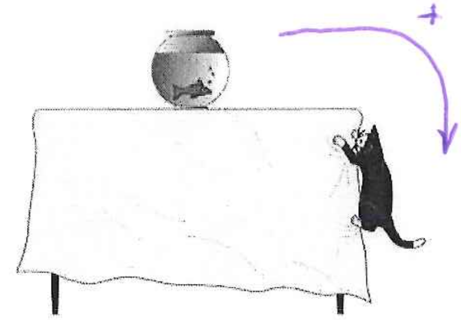
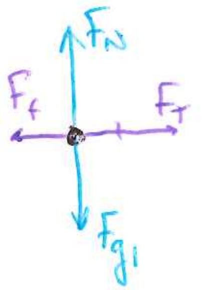


FIGURE 4–50



a. cleo: $\Sigma F = F_T - F_f = m_c a$

figaro: $\Sigma F = F_{g2} - F_T = m_f a$

$m_f g - F_T = m_f a$

$F_T = m_f g - m_f a$

substitute into cleos equation

$F_T - F_f = m_c a$

$m_f g - m_f a - \mu F_N = m_c a$

$m_f g - m_f a - \mu m_c g = m_c a$

$5(9.8) - 5a - .44(11)(9.8) = 11a \rightarrow$ $a = .098\ m/s^2$

b. $\Delta x = v_i t + \frac{1}{2} a t^2$

$.9 = 0 + \frac{1}{2}(.098)t^2$

$t = 4.286\text{sec}$

2. A small mass m is set on the surface of a sphere, Fig. 4-51. If the coefficient of static friction is $\mu_s = 0.60$, at what angle ϕ would the mass start sliding? [Hint: compare to Fig. 4-48; how are θ and ϕ related?

$\theta = \phi$ so find θ and you know ϕ

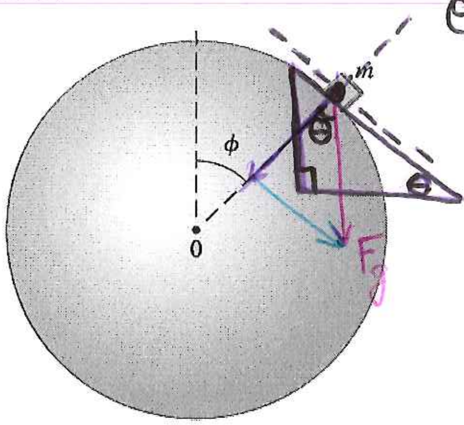


FIGURE 4–51

it will slide when $F_g \sin\theta > F_f$

so: $F_g \sin\theta > \mu F_N$

$F_g \sin\theta > \mu F_g \cos\theta$

$mg \sin\theta > \mu mg \cos\theta$

$9.8 \sin\theta > .6(9.8)\cos\theta$

$\tan\theta > .6$

$\theta > 30.96°$

therefore, $\phi = 30.96°$

3. Police lieutenants, examining the scene of an accident involving two cars, measure the skid marks of one of the cars, which nearly came to a stop before colliding, to be 80 m long. The coefficient of kinetic friction between rubber and the pavement is about 0.80. Estimate the initial speed of that car assuming a level road.

$\Delta x = 80m$

$\mu = .8$

$v_f = 0 m/s$

$a = ?$

$v_i = ?$

First find a: $\Sigma F = -F_f = ma$

$-\mu f_N = ma$

$-\mu mg = ma$

$-.8(9.8) = a \rightarrow a = -7.84 m/s^2$

Now use Kinematics:

$v_f^2 = v_i^2 + 2a\Delta x$

$0 = v_i^2 + 2(-7.84)(80)$

$v_i = 35.42 m/s$

Concept Questions

1. Can a coefficient of friction exceed 1.0?

No! Always between 0 and 1.

2. A block is given a push so that it slides up a ramp. After the block reaches its highest point, it slides back down. Why is the magnitude of its acceleration less on the descent than on the ascent?

On the way up, friction and gravity work in the same direction on the way down they work in opposite directions.

3. A heavy crate rests on the bed of a flatbed truck. When the truck accelerates, the crate remains where it is on the truck, so it too, accelerates. What force causes the crate to accelerate?

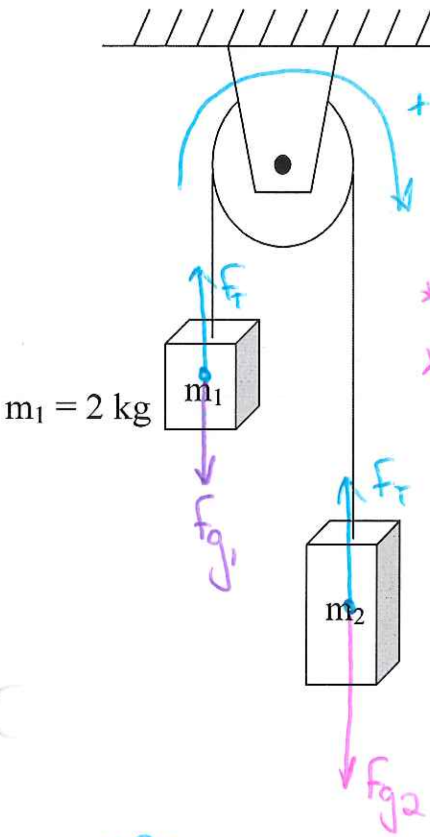
Friction!

4. You can hold a heavy box against a rough wall and prevent it from slipping down by pressing only horizontally. How can the application of a horizontal force keep an object from moving vertically?

By pressing against the wall, you create a normal force which then creates a frictional force to keep it from sliding down.

Lesson 6: Force applications

Atwood Machines (Pulleys)



Always define the direction of motion first! Pick your positive direction

Assumptions
1. Massless, Frictionless Pulley
2. Massless rope that doesn't stretch

Problem Solving
1. Coupled System Approach
   And/Or
2. Individual Force Diagram for each object

Find the tension in the rope and the acceleration of the system

Method 1: Write out one ΣF equation for the entire system making sure to be careful of the signs.

$$\Sigma F = -F_{g_1} + \cancel{F_T} - \cancel{F_T} + F_{g_2} = (m_1+m_2)a$$

$$-m_1 g + m_2 g = (m_1+m_2)a$$

$$-2(9.8) + 10(9.8) = 12a$$

$$8(9.8) = 12a$$

$$\boxed{a = 6.533\ m/s^2!}$$

*NOTE: the systems method won't allow you to find F_T. You need to go look at one object now. Either will give the same answer.

Method 2: Look at each object separately and solve a system of equations.

$$m_1: F_T - F_{g_1} = m_1 a \rightarrow F_T = m_1 a + m_1 g$$

$$m_2: F_{g_2} - F_T = m_2 a$$

$$m_2 g - (m_1 a + m_1 g) = m_2 a$$

$$10(9.8) - 2a - 2(9.8) = 10a$$

$$8(9.8) = 12a$$

$$78.4 = 12a \rightarrow \boxed{a = 6.533\ m/s^2}$$

$$F_T = m_1 a + m_1 g$$

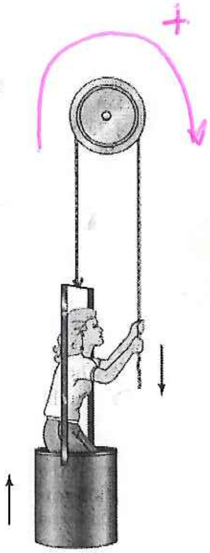
$$= 2(6.533) + 2(9.8) \rightarrow \boxed{F_T = 32.6\overline{6}\ N}$$

Lesson 6 Problems: Force Applications

Problems

1. A window washer pulls herself upward using the bucket-pulley apparatus show in Fig. 4-42. (a) How hard must she pull downward to raise herself slowly at constant speed? (b) If she increases this force by 10 percent, what will her acceleration be? The mass of the person plus the bucket is 65 kg.

FIGURE 4-42



$F_A = F_T$, F_g, F_A

a. $\Sigma F = F_A + F_A - F_g = ma = 0$

$2F_A - mg = 0$

$2F_A = 65(9.8) \rightarrow \boxed{F_A = 318.5N}$

b. $F_A = 318.5 + .1(318.5) = 350.35N$

$\vec{F}_A + \vec{F}_A - mg = ma$

$2(350.35) - 65(9.8) = 65a \rightarrow \boxed{a = .98\ m/s^2}$

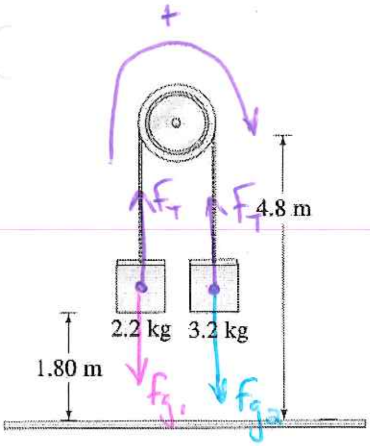


FIGURE 4-45

2. The two masses shown in Fig. 4-45 are each initially 1.80 m above the ground, and massless frictionless pulley is 4.8 m above the ground. What maximum height does the lighter object reach after the system is released? [Hint: First determine the acceleration of the lighter mass and then its velocity at the moment the heavier on hits the ground. This is its "launch" speed]

First find the acceleration:

$\Sigma F = -F_{g1} + F_T - F_T + F_{g2} = (m_1+m_2)a$

$-m_1 g + m_2 g = (m_1+m_2)a$

$-2.2(9.8) + 3.2(9.8) = 5.4a$

$a = 1.8148\ m/s^2$

Now find "launch velocity"

$\Delta x = 1.8m$

$v_i = 0\ m/s$

$a = 1.8148\ m/s^2$

$v_f^2 = v_i^2 + 2a\Delta x$

$= 0^2 + 2(1.8148)(1.8)$

$v_f = 2.556\ m/s$

Now use $a = -9.8\ m/s^2$ since its a projectile and find how high it goes in air.

$v_i = 2.556\ m/s$

$a = -9.8\ m/s^2$

$v_f = 0\ m/s$

$v_f^2 = v_i^2 + 2a\Delta y$

$0 = 2.556^2 + 2(-9.8)\Delta y$

$\Delta y = .33m$

so total height $= 2(1.8m) + .33m = \boxed{3.93m}$

Lesson 7: Inertial Reference Frames

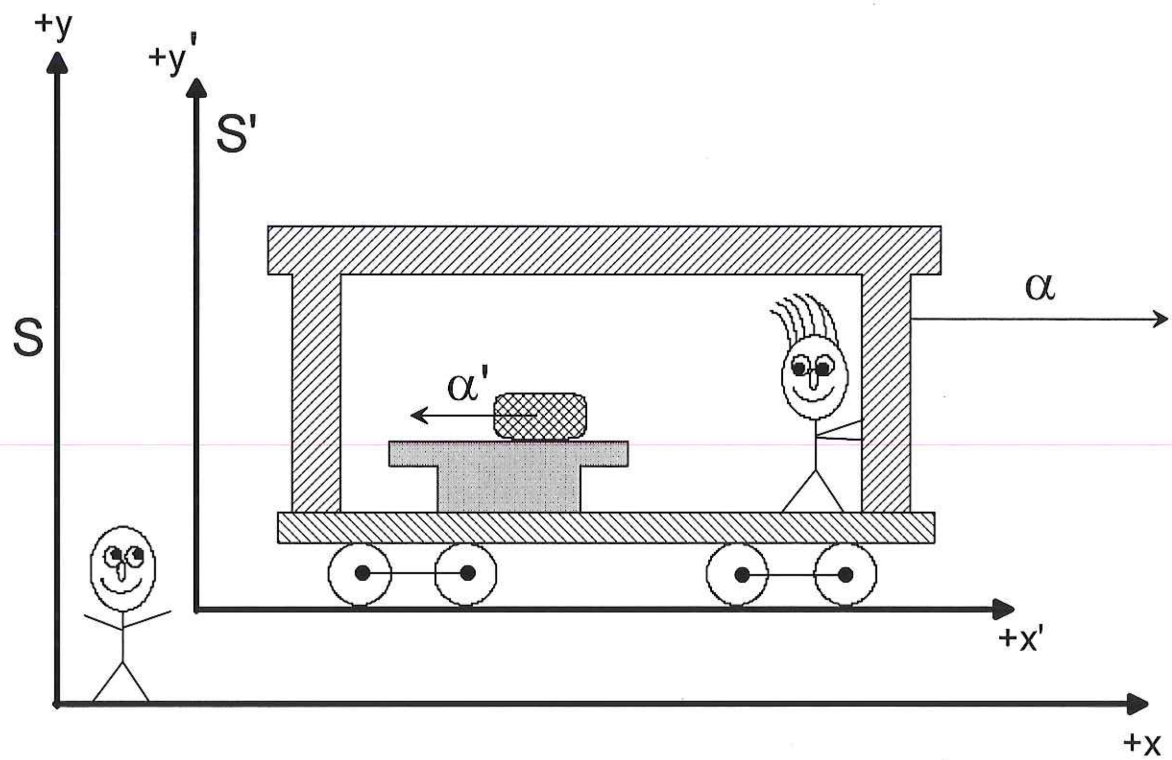
Inertial Reference Frame – Any reference frame in which Newton's Laws Hold.

At Rest ($\vec{v} = 0$) Is an example of an inertial reference frame. The earth can be considered to be "at rest" relative to object moving on its surface.

Constant Velocity ($\Delta\vec{v} = 0$) Is another example of an inertial reference frame.

If you are in a reference frame moving with zero acceleration, (constant velocity) your motion can not be detected experimentally.

Consider the case in which S is an inertial reference frame, and S′ is a reference frame accelerating relative to S.



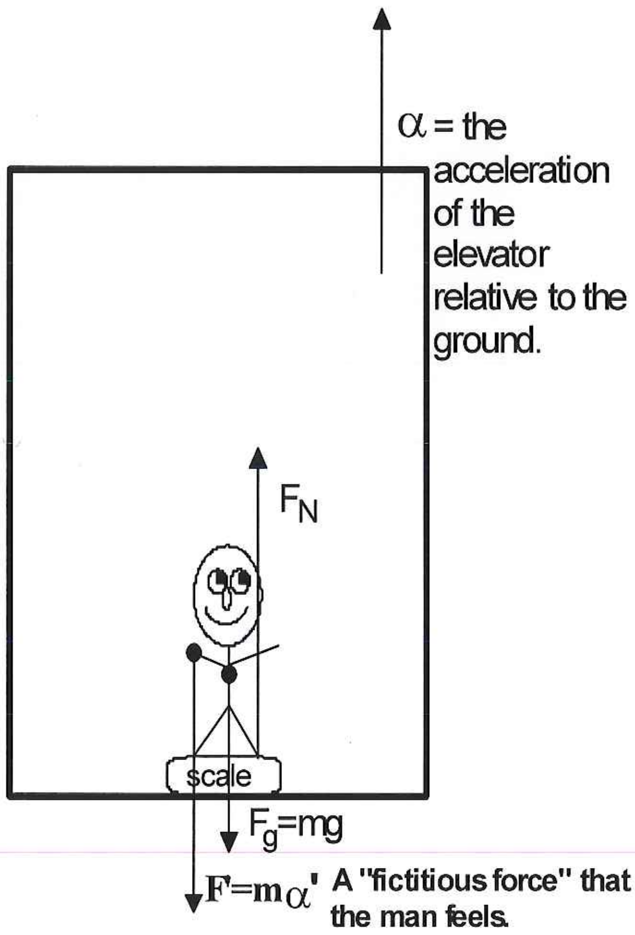
Newton's laws will **not** hold in the railroad car.

In the railroad car, a body at rest on a smooth table does not appear to remain at rest or move with a constant velocity. It appears to accelerate with an acceleration equal to α′.

Accelerating Frames of reference are called ***Non-Inertial*** reference frames.

Example: Non-Inertial Reference Frame

Calculate the "apparent" weight of a 60 kg man in an elevator that is accelerating upward with an acceleration of 2.0 m/s^2.



From the man's non-inertial reference frame:

$$\sum F = 0 = F_N + mg + F'$$

because the $F_N \neq -mg$, the man believes there must be another force acting (F′).

From an observe in an inertial reference frame:

$$\sum F = m\alpha = F_N + mg$$

the inertial observer can see that the man ***IS*** accelerating, and therefore would find that what the man calls **F′** is equal and opposite to the NET Force.

Lesson 7 Concept Questions: Frame of Reference

1. Identify each frame of refere4nce below as inertial or Non-inertial

a) A child revolving around a merry go round. Non-Inertial

b) A reference frame attached to the earth. Inertial

c) A driver in a car moving at a constant velocity. Inertial

d) A pilot taking off on a runway Non-Inertial